(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 653 740 A2**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **94300695.7**

(51) Int. Cl.[6]: **G09G 3/28**

(22) Date of filing: **31.01.94**

(30) Priority: **17.11.93 JP 288345/93**

(43) Date of publication of application:
17.05.95 Bulletin 95/20

(84) Designated Contracting States:
DE FR GB

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(54) Controlling the gray scale of plasma display devices.

(57) A method of controlling the gray scale of a plasma display device has a forming step of forming a frame for an image by a plurality of subframes each having a different brightness, a setting step of setting the number of sustain emissions of the each subframe individually for each subframe, and a displaying step of displaying the image on the plasma display device by a gray scale display having a specific brightness. The number of sustain emissions in each subframe is set individually by the individual subframe, and this can establish a linear relation between the gray level and the corresponding brightness. Therefore, an enhancement of display quality of the plasma display device can be realized.

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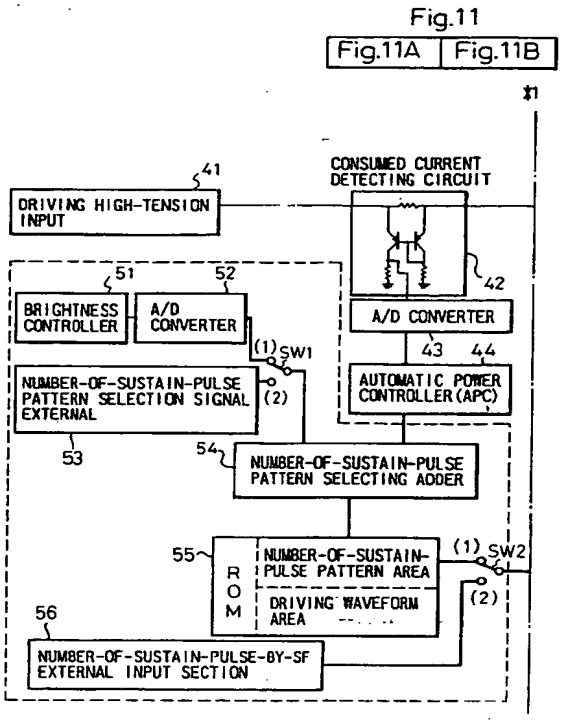
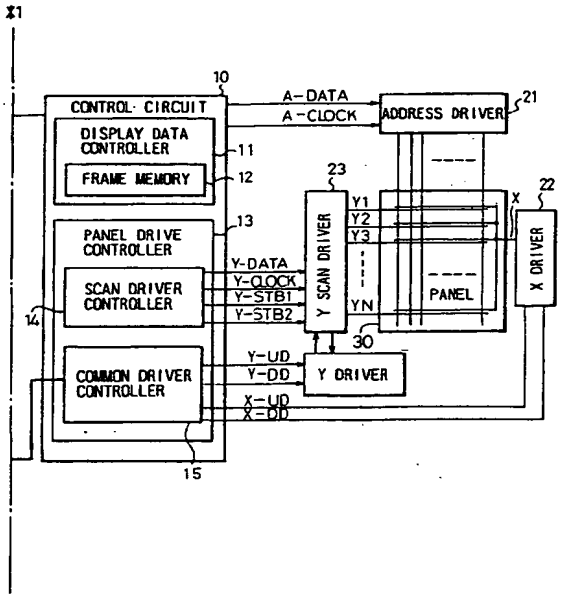
Fig.11A

Fig.11B

Fig.11





The present invention relates to controlling the gray scale of plasma display devices, for example a method and an apparatus for controlling the gray scale of a three-electrode surface-discharge alternating current plasma display device.

Consideration has been given to alternating current plasma display panel (AC PDP) in which luminescence and display is done by applying a voltage wave-form to two sustain electrodes alternately to maintain discharge. In this AC PDP, a discharge operation is carried out in one to several microseconds (μ s) just after the pulse application. Further, ions (positive charges) produced by the discharge accumulate on the surface of the dielectric layer on the electrode to which a negative voltage is being applied and similarly electrons (negative charges) accumulate on the surface of the dielectric layer of the electrode to which a positive voltage is being applied.

When applying a pulse (sustain pulse) of a lower voltage (sustain voltage or sustain discharge voltage) with a different polarity after first discharging with higher voltage (write voltage) pulse (write pulse) to produce wall charges, previously accumulated wall charges are overlapped yielding a high voltage with respect to the discharge space, the voltage exceeding the threshold voltage value of discharge, which causes a discharge to begin. That is, there is a characteristic that once a cell is written to discharge generated wall charges, the discharge is sustained by applying sustain pulses alternately in opposite polarity. It is called a memory effect or a memory function

An AC PDP may make use of the memory effect. Regarding AC PDPs, there has been considered a two-electrode type in which selective discharge (address discharge) and sustain discharge are carried out with two electrodes, and a three-electrode type in which the third electrode is used for address discharge. In an color PDP used for a color display, a phosphor formed in a discharge cell is excited by ultraviolet rays generated by the discharge. However, there is a disadvantage that the phosphor is easily affected by bombardment of ions (positive charges) generated concurrently by discharge.

In the above mentioned two-electrode type, the arrangement is such that ions strike directly against phosphors, which is likely to lead to a reduction in the life of the phosphors. In order to avoid this, a three-electrode arrangement may be used, making use of surface discharge in a color PDP. Further, in such a three-electrode type, it is possible to form the third electrode on the substrate on which the first and second electrode for sustain discharge are disposed, or to form it on another substrate facing the former. Also, in case of forming the said third electrode on the same substrate, it is possible to dispose the third electrode on the two electrodes for sustain discharge or to dispose it under them. Furthermore, in some cases visible light emitted from phosphors may be viewed through the phosphors, and in other cases reflected light from the phosphors may be viewed. In this specification, explanations are given taking an example of a panel in which the third electrode is formed on the substrate different from and facing that of electrodes for sustain discharge.

Higher level gray scales with many display lines have become desirable in an AC PDP as a result of requirements for a larger display size, a larger number of pixels (cells) and full color display in a display panel. Further, it is desirable for an AC PDP to control the gray scale thereof by desired brightness, or appropriate brightness.

It is desirable to provide a gray scale controlling method for a plasma display device which enhances the display quality of the plasma display device by establishing a linear relation between the gray level and the corresponding brightness.

An embodiment of the present invention serves to control the gray scale of a plasma display device by forming a frame for an image by a plurality of subframes each having a different brightness, setting the number of sustain emissions of the each subframe individually for each subframe, and displaying the image on the plasma display device by a gray scale display having a specific brightness.

The plasma display device may be a three-electrode surface discharge AC plasma display device. The three-electrode surface discharge AC plasma display device may comprise first and second electrodes arranged in parallel with each other, and third electrodes orthogonal to the first and second electrodes, the first electrode being commonly connected together, and the second electrodes being arranged for display lines, respectively, wherein the display device has a surface discharge structure employing wall charges as memory media. The three-electrode surface discharge AC plasma display device may further comprises a first substrate, and the first and second electrodes being arranged in parallel with each other on the first substrate and paired for respective display lines; a second substrate spaced apart from and facing the first substrate, and the third electrodes being arranged on the second substrate away from and orthogonal to the first and second electrodes; a wall charge accumulating dielectric layer covering the surfaces of the first and second electrodes; a phosphor formed over the second substrate; a discharge gas sealed in a cavity defined between the first and second substrates; and cells formed at intersections where the first and second electrodes cross the third electrodes.

The number of sustain emissions of the each subframe may be so calculated, on the basis of actually measured data of the brightness with respect to the numbers of sustain emissions, that the brightness obtained by the first subframe having an arbitrary brightness may be twice the brightness obtained by the second subframe having a brightness next to that of the first subframe. The number of sustain emissions in the each subframe may be set in an anti-geometrical progression.

The number of sustain emissions of the each subframe may be so calculated, on the basis of actually measured data of the brightness with respect to the numbers of sustain emissions, that the sum of the squares of errors with the ideal values in the each gray level may become minimum, in order to make the relation between the gray level and the corresponding brightness linear.

The number of sustain emissions of the each subframe may be so calculated, on the basis of actually measured data of the brightness with respect to the numbers of sustain emissions, that the sum of the absolute values of errors with the ideal values in the each gray level may become minimum, in order to make the relation between the gray level and the corresponding brightness linear.

The brightness of the second subframe having next larger gray level than that of the first subframe may not exceed the brightness of the first subframe, for the brightness of the first subframe having the arbitrary gray level. The sum of the numbers of sustain emissions of one or two subframes in the plurality of subframes, or the sum of the numbers of sustain emissions of two or three subframes may be specified. The brightness of the subframe having the maximum gray level may be specified in the plurality of subframes.

Further, an embodiment of the present invention may be put into effect by a three-electrode surface-discharge AC plasma display device comprising first and second electrodes arranged in parallel with each other; and third electrodes orthogonal to the first and second electrodes, the first electrode being commonly connected together, and the second electrodes being arranged for display lines, respectively, wherein the display has a surface discharge structure employing wall charges as memory media, the plasma display device is driven by separate address periods in which display data are written in the whole screen by forming a wall charge, the wall charge is necessary for sustain discharge according to the display data from sustain discharge periods in which sustain discharge for light emission is repeated, one frame forming an image is constituted by a plurality of subframes each having a different brightness, the number of sustain emissions of the each subframe is individually set for the each subframe, and the image is displayed on the plasma display device by a gray scale display having a predetermined brightness.

The plasma display device may further comprise a first substrate, and the first and second electrodes being arranged in parallel with each other on the first substrate and paired for respective display lines; a second substrate spaced apart from and facing the first substrate, and the third electrodes being arranged on the second substrate away from and orthogonal to the first and second electrodes; a wall charge accumulating dielectric layer covering the surfaces of the first and second electrodes; a phosphor formed over the second substrate; a discharge gas sealed in a cavity defined between the first and second substrates; and cells formed at intersections where the first and second electrodes cross the third electrodes.

The plasma display device may further comprise a memory unit for setting and storing the number of sustain emissions in each subframe, and information on the number of sustain emissions in the each subframe may be read at any time from the memory unit.

The memory unit may be constituted by a vacant area of a driving wave-form memory device in the plasma display device, and the information on the number of sustain emissions in the each subframe may be set in the vacant area of the driving wave-form memory device. The plasma display device may further comprise a brightness controller for adjusting the brightness, and the brightness controller may select one piece from the information on the number of sustain emissions in the each subframe set in the memory unit. The number of sustain emissions in the each subframe may be set as a plurality of combinations in the memory unit, and an arbitrary one of the plurality of combinations may be selected by unit of selection signals supplied from the outside of the plasma display device.

The plasma display device may further comprise a consumed current controller unit for controlling and keeping the consumed current below a predetermined value, the number of sustain emissions in the each subframe may be set as a plurality of combinations in the memory unit, an arbitrary one of the plurality of combinations may be selected in response to the output from the consumed current controller unit, and thereby the power consumption may be kept constant regardless of the change of display rate. The information on the number of sustain emissions in the each subframe may be supplied from outside the plasma display device.

Reference will now be made, by way of example, to the accompanying drawings, in which:

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Fig. 1 is a plan diagram schematically showing an arrangement of a previously-considered three-electrode surface-discharge AC-driven plasma display panel;

Fig. 2 is a sectional diagram schematically showing an arrangement of a discharge cell in the plasma display panel of Fig. 1;

Fig. 3 is a block diagram showing an example of a three-electrode surface-discharge AC-driven plasma display device using the plasma display panel shown in Fig. 1;

Fig. 4 is a diagram showing an example of driving waveforms in a plasma display device of Fig. 3;

Figs. 5A to 5D are diagrams illustrating how cells are driven in the plasma display device of Fig. 3;

Fig. 6 is a timing chart showing an example of a driving operation for the plasma display device of Fig. 3;

Fig. 7 is a diagram showing problems in the conventional gray scale controlling method of a plasma display device;

Fig. 8 is a diagram for explaining an embodiment of a gray scale controlling method for a plasma display device embodying the present invention;

Fig. 9 is a diagram for explaining another embodiment of a gray scale controlling method for a plasma display device embodying the present invention;

Fig. 10 is a diagram for explaining still another embodiment of a gray scale controlling method for a plasma display device embodying the invention; and

Fig. 11, consisting of Figs. 11A and 11B, is a block diagram showing an embodiment of a plasma display device to which a gray scale controlling method for a plasma display device embodying the present invention is applied.

Figure 1 shows an arrangement of a three-electrode surface-discharge AC-driven plasma display panel considered previously, and Fig. 2 shows an arrangement of a discharge cell in the plasma display panel of Fig. 1. Note that Fig. 1 shows the arrangement (electrode arrangement) constituted by an M x N dot panel.

In Figs. 1 and 2, reference numeral 1 denotes a front glass substrate, 2 denotes a rear glass substrate, 3 denotes address electrodes, 4 denotes walls, 5 denotes a phosphor, 6 denotes a dielectric layer, 7 and 8 denote X and Y electrodes, respectively. In this AC PDP, discharge operation occurs mainly between the two sustain discharge electrodes (X electrode 7 and Y electrode 8) disposed on the rear glass substrate 2, and the selection of pixels (or discharge cell) according to the display data is done by selecting a cell on the line including the corresponding Y electrode 8 making use of discharge between the Y electrode 8 and the address electrode 3.

Note that, on each sustain discharge electrode 7 and 8, the dielectric layer 6 is formed for insulation, on which a protective layer, or an MgO layer is formed. Further, on the front glass substrate 1 facing the rear glass substrate 2, the address electrodes 3 and phosphors 5 are formed. Note that, the phosphors 5 have red, green and blue light emitting characteristics, and they are formed on the address electrodes 3.

As shown in Fig. 2, a discharge space (cavity) is so separated by the walls (barrier ribs) 4 formed on one side or both sides of the glass substrate that discharge occurs in a space of each cell. Ultraviolet light produced by the discharge causes the phosphor to emit light. Arranging a plurality M x N of cells having such structure, for example, in a matrix state forms a display panel as shown in Fig. 1. Note that, in Fig. 1, references A1 to AM denote address electrodes, and Y1 to YN denote Y electrodes. Further, X electrodes 7 are commonly connected.

Figure 3 is a block diagram showing an example of three-electrode surface-discharge AC-driven plasma display device using a plasma display panel shown in Fig. 1, and shows peripheral circuits for driving a typical three-electrode AC PDP.

In Fig. 3, reference numeral 10 denotes a control circuit, 11 denotes a display data controller, 12 denotes a frame memory, 13 denotes a panel drive controller, 14 denotes a scan driver controller, and 15 denotes a common driver controller. Further, reference numeral 21 denotes an address driver, 22 denotes an X driver, 23 denotes a Y scan driver, 24 denotes a Y driver, and 30 denotes a plasma display panel (PDP). Further, in Fig. 3, reference mark CLOCK denotes a dot clock indicating display data, DATA denotes display data (in case of 256 gray scales, 8 bits for each color: 3 x 8), VSYNC denotes a vertical synchronizing signal, which indicates the beginning of a frame (one field), and HSYNC denotes a horizontal synchronizing signal.

The control circuit 10 comprises a display data controller 11 and a panel drive controller 13. The display data controller 11 stores display data in the frame memory 12 and transfers the data to the address driver 21 to drive the panel. Note that reference mark A-DATA denotes display data, and A-CLOCK denotes a transfer clock.

The panel drive controller 13 decides when to apply a high voltage wave (pulse) to the panel 30 and is provided with the scan driver controller 14 and the common driver controller 15. Note that reference mark Y-DATA denotes scan data (data for turning ON the Y scan driver 23 every bit), Y-CLOCK denotes a

transfer clock (a clock for turning ON the Y scan driver 23 every bit), Y-STB1 denotes a Y strobe-1 (a signal for regulating the timing of turning on the Y scan driver), and Y-STB2 denotes a Y strobe-2. Further, reference mark X-UD denotes a signal (outputs Vs/Vw) for controlling the ON/OFF of the X common driver (22), X-DD denotes a signal (GND) for controlling the ON/OFF of the common driver, Y-UD denotes a signal (outputs Vs/Vw) for controlling the ON/OFF of the Y common driver (24), and Y-DD denotes a signal (GND) for controlling the ON/OFF of the Y common driver.

As shown in Fig. 3, each of the address electrodes 3 is connected to the address driver 21 and gets an address pulse of the address discharge time from the address driver. Further, the Y electrodes 8 are individually connected to the Y scan driver, and the Y scan driver 23 is connected to the Y common driver (Y driver 24). The pulse of address discharge time is generated from the Y scan driver 23, and the sustain pulses and others come from the Y driver 24 and are applied to the Y electrodes 8 through the Y scan driver 23. Further, the X electrodes 7 are commonly connected over the display lines of the panel 30, and the X common driver (X driver 22) generates write pulses, sustain pulses, and the like. These driver circuits (21, 22, 23, 24) are controlled by the control circuit 10, which is controlled by synchronous signals, display data signals and others supplied from outside of the device.

Figure 4 is a chart showing an example of driving wave-forms in a plasma display device of Fig. 3, that is, Fig. 4 shows driving waveforms of one subframe (or one subfield) in the so-called "address/sustain discharge separated write addressing method". This address/sustain discharge separated write addressing method is, for example, disclosed in Japanese Patent Application No. 3-338342. In that Japanese Application, a driving method intended for low voltage and steady driving (or addressing) is disclosed, and the method is applied to the case when a higher level gray scale technologies for a full color display is required.

As shown in Fig. 4, one subframe is separated into an address period and a sustain discharge period. In the address period, a whole-screen writing, a whole screen erasing and a sequential addressing by writing into display line (hereinafter, referred to as "line sequential writing (or addressing)") are carried out. Further, in a sustain discharge period, sustain pulses are applied to all of the lines simultaneously, which results in sustain discharges in the cells which write addressing has been executed to and wall charges has been accumulated in. Note that, if a frame consists of two subframes for example by means of interlace (leap over) operation, one subframe corresponds to a subfield in each subframe.

In the above description, one aspect of the driving method shown in Fig. 4 is that the states of all the cells are equalized by whole-screen writing and whole-screen erasing which are carried out at the beginning of the address period and the whole-screen erasing is completed in the state where wall charges available in the subsequent line sequential writing discharge remain.

First, the Y electrodes are brought to the GND level, and at the same time, write pulses of the voltage Vw are applied to the X electrodes causing the whole-screen writing. At this time, ions of positive charges are accumulated to the address electrode, in reality on the surface of dielectric material such as phosphor. Further, in the next step, by applying erasing pulses of the voltage Ve, the whole-screen erasing is carried out. In the erasing discharge, which makes the state in which there is no wall charge on the surface of the dielectric layer (MgO layer) of the X and Y electrodes, it is preferable to accumulate electrons, negative charges advantageous in the next addressing discharge on the MgO surface of Y electrode. Note that the voltage value of the residual wall charges should be at such a level as not to cause the sustain discharge even when sustain discharge pulses are applied to the X and Y electrodes.

After the whole-screen writing and whole-screen erasing intended for the equalization and low voltage operation, a line sequential writing discharge (or addressing discharge) is carried out. In the discharge (discharge operation), the Y electrode of the line to be written is brought to the GND level and an address pulse of the voltage Va is applied to the address electrode of the cell to be written in the line. At this time, the address discharge is possible with a very low voltage because ions and electrons have accumulated on the address side (the surface of the phosphor) and on the Y electrode side (the MgO surface) respectively. After these operations have been executed all over the lines, sustain pulses are applied to X and Y electrodes alternately for the sustain discharge.

Figures 5A to 5D are diagrams illustrating how cells are driven in the plasma display device of Fig. 3. Namely, Figs. 5A to 5D show diagrams of the arrangement of charges within a discharge cell and the state of discharge. Namely, Fig. 5A shows the whole-screen (or overall) writing step (Positive charges (or ions) have accumulated on the address electrode.), Fig. 5B shows the whole-cell sustain discharge step, and Fig. 5C shows the whole-cell erasing step (The wall charge of the sustain discharge electrode is reduced to such a value as not to cause discharge even when sustain discharge voltage (Vs) is applied). Note that, if negative wall charges (electrons) are permitted to remain on the Y electrode, they effectively affect the next address discharge. Further, Fig. 5D shows the selective writing step (address discharge: Writing discharge

is done utilizing the wall charge of the address electrode).

First, as shown in Fig. 5A, in the whole-cell writing step, ions are accumulated on the address electrode 3, and ions and electrons are accumulated as wall charges on the X electrode 7 and the Y electrode, respectively. Next, as shown in Fig. 5B, in the whole-cell sustain discharge step, the ions of the address electrode 3 are left as they are and the sustain discharge between the X electrode 7 and the Y electrode 8 causes the inversion of charges. Further, as shown in Fig. 5C, in the whole-cell erasing step, the ions of the address electrode 3 are left as they are and the erasing discharge between the X electrode 7 and the Y electrode 8 reduces the wall charges to such a value as not to cause sustain discharge even when sustain discharge pulses of the voltage Vs is applied.

Further, as shown in Fig. 5D, in the selective writing step, a line sequential selective writing discharge (or addressing discharge) is carried out. Though the voltage applied at this time from the electrode is not more than the voltage Va of address pulses applied to the address electrode 3, the selective writing discharge (or addressing discharge) can be executed surely and steadily with a low address voltage Va because the voltage owing to the wall charges which have been produced until the whole-cell erasing step. Namely, the voltage on the ions of the address electrode 3 and the electrons of the Y electrode 8 functions accumulatively with the address voltage Va.

Therefore, "the address/sustain discharge separated addressing method" is used in cases when there are many scan lines (or display lines) or when higher level gray scale is used for full color display. This method is, for example, disclosed in Japanese Unexamined Patent Publication (Kokai) No. 4-195188. Further, the driving method in case of the 16 gray scales is shown as an example of a high gray level display in Fig. 6.

Figure 6 shows timing chart for driving the plasma display device of Fig. 3, and shows the driving method in case of the 16 gray scales. In the driving method as shown in Fig. 6, one frame is divided into four subframes (or subfields) SF1, SF2, SF3, and SF4. In these subframes, the address periods Ta1, Ta2, Ta3, and Ta4 including the whole-screen writing periods Tw1, Tw2, Tw3, and Tw4 are of the identical length (time). Further, the lengths (periods of time) of the sustain discharge periods Ts1, Ts2, Ts3, and Ts4 are of the rate 1:2:4:8. Therefore, it is possible to display in 16 scales of brightness from 0 to 15 by selecting subframes to be lightened.

As described above, in an AC PDP, a frame which forms an image (picture) consists of some sheets of subframes different in brightness from each other. The luminous brightness of each subframe is decided by the number of sustain discharge per unit time. Ideally, the brightness has a linear relationship with the number of sustain discharges. Therefore, the method in which the number of sustain discharge pulses of any subframe is half of that of the subframe next brighter than the former is the best.

Further, the Japanese Patent Application No. 4-281459 "The Driving Method Relating to The Adjustment of Brightness of A Plasma Display Panel" has been filed at the Japanese Patent Office. That application suggests, for example, that in the case of the 16 gray scales, 4 subframes are required. The number of sustain discharge pulses within each Vsync is, if 80 pulses in the SF (SF4) of the maximum brightness, 40 pulses in subframe SF3, 20 pulses in subframe SF2, and 10 pulses in subframe SF1.

Figure 7 is a diagram illustrative of the problems in a previously consider gray scale controlling method of a plasma display device, and shows the relationship between the number of sustain pulses and the brightness.

As shown in a solid line in Fig. 7, ideally, the brightness should be in linear relationship with the number of sustain discharges. If so, the relationship of the brightness with respect to the gray level (or the value of gray scale) is also linear.

However, as shown in a dashed line in Fig. 7, in actual displays, the relationship of the brightness with respect to the number of sustain discharges is not linear, but curved. Accordingly, the relationship of the brightness with respect to the gray level is also not linear, which results in remarkable degradation of the display quality. Such a problem is becoming significant with the requirement of increase in the gray scale number in recent years. As to higher level gray scale display such as the 64 gray scales, the above mentioned degradation of the display quality becomes a serious problem.

Below, examples of a method and an apparatus for controlling the gray scale of a plasma display device according to embodiments of the present invention will be explained with reference to the drawings.

Figure 8 shows an embodiment of a gray scale controlling method for a plasma display device according to the present invention. In Fig. 8, the axis of ordinates indicates the brightness B [cd/mxm), the axis of abscissas indicates the gray level.

Note that, in each of the following embodiments, the gray level 0 corresponds to the case when no sustain emission is done in any subframe (or subfield) SF1 through SF3, the gray level 1, 2, and 4 correspond to the case when sustain emissions of only one subframe SF1, SF2, or SF3 are done, the gray

level 3, 5 and 6 correspond to the case when sustain emissions of two subframes SF1 and SF2, SF1 and SF3, or SF2 and SF3 are done, and the gray level 7 corresponds to the case when sustain emissions of all the subframes SF1 through SF3 are done.

$$B = f_1(P) \quad \cdots (1)$$

$$B = f_2(K) \quad \cdots (2)$$

$$f_1(P3) = 2 \times f_1(P2) = 4 \times f_1(P1) \quad \cdots (3)$$

$$P1 < P2 < P3 \quad \cdots (4)$$

$$b_1 = f_1(P1) - f_2(1) \quad \cdots (5)$$

$$b_2 = f_1(P2) - f_2(2) \quad \cdots (6)$$

$$b_3 = f_1(P1 + P2) - f_2(3) \quad \cdots (7)$$

$$b_4 = f_1(P3) - f_2(4) \quad \cdots (8)$$

$$b_5 = f_1(P1 \quad P3) - f_2(5) \quad \cdots (9)$$

$$b_6 = f_1(P2 + P3) - f_2(6) \quad \cdots (10)$$

$$b_7 = f_1(P1 + P2 + P3) - f_2(7) \quad \cdots (11)$$

$$bS1 = \sum_{k=1}^{7}(b_k') \quad \cdots (12)$$

$$bS2 = \sum_{k=1}^{7} |b_k| \quad \cdots (13)$$

$$Pn > \sum_{k=1}^{n-1} Pk \quad \cdots (14)$$

First, the brightness B of a panel is measured for some numbers P of sustain discharge pulses to get actually measured values in a gray scale-brightness characteristic as shown in Fig. 7, and the resultant curve is made B=f1(P) of the equation (1). In the previously consider method, the number of sustain emissions in each subframe is so set that the number of pulses in an arbitrary subframe is two times the number of pulses in the subframe next brighter than the former. However, in this embodiment, the number of sustain emissions in each subframe is so set that the brightness of an arbitrary subframe is two times the brightness of the subframe next brighter than the former.

A case of optimization according to the embodiment will be shown exemplifying the actually measured values in the gray scale-brightness characteristic shown in Fig. 7. Assuming the brightness of subframe SF3 to be 60 cd/mxm, the brightness of subframe SF2 is half of 60, 30 cd/mxm, the brightness of subframe SF1, is half of 30, 15 cd/mxm. In this case the numbers of sustain discharge pulses for each gray level are as Table 1 below.

[Table 1]

GRAY LEVEL	0	1	2	3	4	5	6	7
BRIGHTNESS Cd/m^2	0	15	30	43	60	66	71	76
NUMBER OF SUSTAIN DISCHARGE PULSES	0	15	30	45	80	95	110	125

In Fig. 8, the dashed line indicates the relation before the optimization and the solid line indicates the relation after the optimization. The embodiment shown in Fig. 8 has advantage that it does not need complex calculations, but lacks linearity in higher gray levels when the linearity of the brightness B of the panel with respect to the number P of sustain discharge pulses is low. Namely, the numbers of sustain emissions of each subframe are like a geometric series (1, 2, 4, 8, ...) in the conventional gray scale controlling method, whereas the numbers of sustain emissions of each subframe is set on the basis of the brightness of the each subframe in the embodiment's gray scale controlling method for the plasma display

device. Therefore, the numbers of sustain emissions of each subframe are not like a geometric series in the inventive gray scale controlling method for a plasma display device. Namely, the number of sustain emissions in each subframe is set in an anti-geometrical progression, or the number of sustain emissions in each subframe is not determined in accordance with any mathematical relationship.

Figure 9 shows another embodiment of a gray scale controlling method for a plasma display device in accordance with the invention, and Fig. 10 is a diagram for explaining still another embodiment of a gray scale controlling method for a plasma display device in accordance with the invention. In Figs. 9 and 10, the axis of ordinates indicates the brightness B [cd/mxm], the axis of abscissas indicates the gray level.

As shown in Fig. 9, in this embodiment the target line of the brightness B for gray levels is set to B = f2-(K) of the equation (2). Note that, assuming the difference between a calculated brightness and a target brightness in a certain gray level X in a certain sustain pulse number ratio to be bx, it is possible to find the numbers (P1, P2, P3) of sustain pulses of each subframe, for example, in the 8 gray scales in the following procedure.

The optimum numbers of sustain pulses are such, P1, P2, and P3, as to minimize bS1 in the equation (12) which satisfies the conditions of the equations (4) to (11) when the equation (1) is obtained in first by actual measurement and the equation (2) is set. In other words, in order to make the relation between the gray level and the corresponding brightness a linear relation, the numbers of sustain emissions of each subframe in case when the sum of the squares of errors in each gray level with respect to the ideal values becomes minimum is calculated on the basis of data of the brightness actually measured for the numbers of sustain emissions. In the embodiment shown in Fig. 9, the calculations are complex as compared with the embodiment shown in Fig. 8, but a result very close to optimum can be found.

It should be noted that though the numbers of sustain emissions of each subframe in case when the sum of the squares of errors in each gray level with respect to the ideal values becomes minimum is calculated in the equation (12), using the equation (13) instead of the equation (12), it is possible to calculate the numbers of sustain emissions of each subframe in case when the sum of the absolute values of errors in each gray level with respect to the ideal values becomes minimum. In other words, in order to make the relation between the gray level and the corresponding brightness a linear relation, the numbers of sustain emissions of each subframe in case when the sum of the absolute values of errors in each gray level with respect to the ideal values becomes minimum is calculated on the basis of data of the brightness actually measured for the numbers of sustain emissions.

When the equation (12) or (13) is used, there is the possibility of bring about the situation in which for the brightness of an arbitrary gray level, the brightness of the gray level next larger than the former exceeds that of the former. In order to avoid this, the condition of equation (14) is added. The equation (14) indicates that the number of pulses of an arbitrary subframe exceeds the sum of the numbers of the pulses of the subframes which has less pulses than the former subframe. That is, it is possible to make such arrangement that for the brightness of the first subframe with an arbitrary gray level, the brightness of the second subframe which has a next larger gray level than the first subframe never exceeds that of the first subframe.

Further, in order to obtain higher brightness, the number of sustain pulses of each subframe may be increased. However, the number of sustain pulses which can be included in a limited time within a vertical synchronous period has a limitation. Thus, if the sum (P1 + P2 + P3) of the numbers of pulses within a vertical synchronous signal or the number (P3) of pulses of the highest level subframe is first set, and then P1, P2 and P3 in case when bS1 of the equation (12) or bS2 of the equation (13) which satisfies the conditions of the equations (4) to (11) becomes minimum are found, then they are the optimum number of sustain pulses. In this case, there is no need for setting B = f2(K) of the equation (2). Note that the number of pulses of SF3 is set for 60 in the embodiment in Fig. 9. That is, an arrangement may be so made that the sum of the numbers of sustain emissions of one or two subframes in a plurality of subframes, or the sum of the numbers of sustain emissions of two or three subframes is specified. Note that, when the number of the subframes is increased, the number of the subframes to be specified the sum becomes increased.

Next if there is a sufficiently long vertical synchronous period as shown in Fig. 10 and the target maximum brightness needs to be set, the maximum brightness f1(P1 + P2 + P3) is first set, and then P1, P2 and P3 in case when bS1 of the equation (12) or bS2 of the equation (13) which satisfies the conditions of the equations (3) to (10) becomes minimum are found, the resultant values being the optimum number of sustain pulses. In this case, B = f2(K) of the equation (2) need not be set. Note that, in the embodiment of Fig. 10, the brightness of the gray level 7 is set for 140 cd/mxm. Namely, an arrangement may be so made that the brightness of the subframe with the maximum gray level is specified.

Using the optimum number of sustain discharge pulses found through each method as described above, the driving operation described below will be carried out.

Figures 11A and 11B (Fig. 11) are block diagrams showing an embodiment of a plasma display device to which the presently-proposed gray controlling method for a plasma display device is applied. In Figs. 11A and 11B (Fig. 11B), reference numeral 10 denotes a control circuit, 11 denotes a display data controller, 12 denotes a frame memory, 13 denotes a panel drive controller, 14 denotes a scan driver controller, and 15 denotes a common driver controller. Further, reference numeral 21 denotes an address driver, 22 denotes a X driver, 23 denotes a Y scan driver, and 30 denotes a plasma display panel (PDP). These components are identical to those shown in Fig. 3, so explanations will be omitted.

In Figs. 11A and 11B (Fig. 11A), reference numeral 41 denotes a high-tension input for driving, 42 denotes a consumed current detecting circuit, 43 denotes an A/D converter, and 44 denotes an automatic power controller (APC). Further, reference numeral 51 denotes a brightness controller, 52 denotes an A/D converter, 53 denotes a number-of-sustain-pulse pattern selection signal external input section, 54 denotes a number-of-sustain-pulse pattern selecting adder, 55 denotes a ROM (read only memory), and 56 denotes a number-of-sustain-pulse-by-SF external input section. Also, reference marks SW1 and SW2 denote selection switches.

The data of the numbers of sustain discharge pulses which are calculated through the above described gray scale controlling method for a plasma display device (the optimum number-of-sustain-emission calculating method) are stored in ROM 55. The data of the numbers of sustain discharge pulses which are output from ROM 55 are supplied to the common driver controller 15 in the control circuit 10, which output control signals for sustain discharge pulses of each subframe by a specified number from ROM 55 in a prescribed timing to the X driver 22 and Y driver 24. The X driver 22 and Y driver 24 output high-tension panel driving pulses on the basis of the control signals supplied from the control circuit 10. That is, the numbers of sustain emissions in each subframe are set in ROM 55 and are read therefrom as occasion demands.

In this case, making good use of a vacant area in ROM which had been used for driving waveforms, instead of adding new ROM, will contribute to cost reduction and saving of the mounting area. In other words, a memory for setting and storing the numbers of sustain emissions in each subframe can be constituted by the vacant area of the driving waveform memory device 55 in the plasma display device.

Furthermore, if the data of the numbers of sustain discharge pulses are calculated and set not only in one kind of pattern but in a plurality of kinds of patterns different in relative brightness using the equations (12) and (13), it becomes possible to adjust the brightness keeping a constant gray scale display. Brightness information set by the brightness controller 51 is converted by the A/D converter 52 into a digital signal, which serves as ROM address signal and selects number-of-sustain-emission data. That is, an arrangement can be so made that one piece is selected by the brightness controller 51 out of information about the numbers of sustain emissions of each subframe which is set in ROM. This enables the user to adjust the brightness to the operating circumstance of the device.

In this case, by shifting the points of contact of the selection switch SW1 from (1) to (2), information from an external device instead of information by the brightness controller 51 can be let in via a number-of-sustain-pulse pattern selection signal external input section 53. Further, information on the number of sustain emissions of a frame may be set as a plurality of combinations in ROM 55, and any one among the plurality of combinations may be selected by means of selection signals supplied from outside of the plasma display device. This enables the remote control of brightness adjustment and so forth.

Further, in the present plasma display device, since the consumed current varies greatly depending on brightness and a display rate, the power supplying route is provided with a consumed current detecting circuit 42 using well known technology, so that the consumed current is controlled and limited to below the set value by limiting the brightness when the consumed current exceeds a prescribed value because of the increase of a display rate and the like. By adding the output of automatic power controller (consumed current controller means) 44 for controlling the consumed current in the number-of-sustain-pulse pattern selecting adder and write the result in ROM 55, it becomes possible to achieve smooth gray scale control limiting the consumed current to below a certain value. Namely, it is possible to make the consumed power constant regardless of the change of a display rate.

The above described plasma display device is so arranged that each control is achieved on the basis of information in ROM (55) provided within the main body of the plasma display device. By the way, the life span of a plasma display device is generally defined as halving of brightness. For example, when it is desirable to do higher level gray scale control from the outside of the unit in order to cope with such a phenomenon, shifting the points of contact of the selection switch SW2 from side (1) to side (2) enables the external input of the number of sustain pulses by subframe (or subfield), and eventually enables real-time

alteration of the number of sustain discharge pulses.

In the above description, a surface-discharge AC plasma display device with three-electrode structure has been described in detail as an example to which the presently-proposed gray scale controlling method for a plasma display device is applied. However, it should be noted that in addition to the three-electrode surface-discharge AC plasma display device, an embodiment of the present invention can be applied to for example, two-electrode facing-discharge plasma display devices and other plasma display devices.

As described above, according to a gray scale controlling method for a plasma display device embodying the present invention, the number of sustain emissions in each subframe is set individually by the each subframe. This establishes a linear relation between the gray level and the corresponding brightness and enables the enhancement of display quality of the plasma display device.

Many different embodiments of the present invention may be constructed without departing from the spirit and scope of the present invention, and it should be understood that the present invention is not limited to the specific embodiments described in this specification, except as defined in the appended claims.

Claims

1. A method of controlling the gray scale of a plasma display device, characterized in that said method comprises the steps of:

   forming a frame for an image by a plurality of subframes each having a different brightness;

   setting the number of sustain emissions of said each subframe individually for said each subframe; and

   displaying the image on said plasma display device by a gray scale display having a specific brightness.

2. A method of controlling the gray scale of a plasma display device as claimed in claim 1, wherein said plasma display device is a three-electrode surface discharge AC plasma display device.

3. A method of controlling the gray scale of a plasma display device as claimed in claim 2, wherein said three-electrode surface discharge AC plasma display device comprises:

   first and second electrodes (7, 8) arranged in parallel with each other; and

   third electrodes (3) orthogonal to said first and second electrodes (7, 8), said first electrode (7) being commonly connected together, and said second electrodes (8) being arranged for display lines, respectively, wherein said display device has a surface discharge structure employing wall charges as memory media.

4. A method of controlling the gray scale of a plasma display device as claimed in claim 3, wherein said three-electrode surface discharge AC plasma display device further comprises:

   a first substrate (2), and said first and second electrodes (7, 8) being arranged in parallel with each other on said first substrate (2) and paired for respective display lines;

   a second substrate (1) spaced apart from and facing said first substrate (2), and said third electrodes (3) being arranged on said second substrate (1) away from and orthogonal to said first and second electrodes (7, 8);

   a wall charge accumulating dielectric layer (6) covering the surfaces of said first and second electrodes (7, 8);

   a phosphor (5) formed over said second substrate (1);

   a discharge gas sealed in a cavity defined between said first and second substrates (2, 1); and

   cells formed at intersections where said first and second electrodes (7, 8) cross said third electrodes (3).

5. A method of controlling the gray scale of a plasma display device as claimed in any one of the preceding claims, wherein the number of sustain emissions of said each subframe is so calculated, on the basis of actually measured data of the brightness with respect to the numbers of sustain emissions, that the brightness obtained by the first subframe having an arbitrary brightness is twice the brightness obtained by the second subframe having a brightness next to that of said first subframe.

6. A method of controlling the gray scale of a plasma display device as claimed in any one of the preceding claims, wherein the number of sustain emissions in said each subframe is set in an anti-

geometrical progression.

7. A method of controlling the gray scale of a plasma display device as claimed in any one of the preceding claims, wherein the number of sustain emissions of said each subframe is so calculated, on the basis of actually measured data of the brightness with respect to the numbers of sustain emissions, that the sum of the squares of errors with the ideal values in said each gray level becomes minimum, in order to make the relation between the gray level and the corresponding brightness linear.

8. A method of controlling the gray scale of a plasma display device as claimed in any one of the preceding claims, wherein the number of sustain emissions of said each subframe is so calculated, on the basis of actually measured data of the brightness with respect to the numbers of sustain emissions, that the sum of the absolute values of errors with the ideal values in said each gray level becomes minimum, in order to make the relation between the gray level and the corresponding brightness linear.

9. A method of controlling the gray scale of a plasma display device as claimed in claim 7 or 8, wherein the brightness of the second subframe having next larger gray level than that of said first subframe does not exceed the brightness of said first subframe, for the brightness of the first subframe having said arbitrary gray level.

10. A method of controlling the gray scale of a plasma display device as claimed in claim 7 or 8, wherein the sum of the numbers of sustain emissions of one or two subframes in said plurality of subframes, or the sum of the numbers of sustain emissions of two or three subframes is specified.

11. A method of controlling the gray scale of a plasma display device as claimed in claim 7 or 8, wherein the brightness of the subframe having the maximum gray level is specified in said plurality of subframes.

12. A three-electrode surface-discharge AC plasma display device comprising:

first and second electrodes (7, 8) arranged in parallel with each other; and

third electrodes (3) orthogonal to said first and second electrodes (7, 8), said first electrode (7) being commonly connected together, and said second electrodes (8) being arranged for display lines, respectively, characterized in that said display has a surface discharge structure employing wall charges as memory media, said plasma display device is driven separating address periods in which display data are written in the whole screen by forming wall charge, said wall charge is necessary for sustain discharge according to said display data from sustain discharge periods in which sustain discharge for light emission is repeated, one frame forming an image is constituted by a plurality of subframes each having a different brightness, the number of sustain emissions of said each subframe is individually set for said each subframe, and the image is displayed on said plasma display device by a gray scale display having a predetermined brightness.

13. A three-electrode surface-discharge AC plasma display device as claimed in claim 12, wherein said plasma display device further comprises:

a first substrate (2), and said first and second electrodes (7, 8) being arranged in parallel with each other on said first substrate (2) and paired for respective display lines;

a second substrate (1) spaced apart from and facing said first substrate (2), and said third electrodes (3) being arranged on said second substrate (1) away from and orthogonal to said first and second electrodes (7, 8);

a wall charge accumulating dielectric layer (6) covering the surfaces of said first and second electrodes (7, 8);

a phosphor (5) formed over said second substrate (1);

a discharge gas sealed in a cavity defined between said first and second substrates (2, 1); and

cells formed at intersections where said first and second electrodes (7, 8) cross said third electrodes (3).

14. A three-electrode surface-discharge AC plasma display device as claimed in claim 12 or 13, wherein said plasma display device further comprises a memory means (55) for setting and storing the number of sustain emissions in each subframe, and information on the number of sustain emissions in said each subframe is read at any time from said memory means (55).

15. A three-electrode surface-discharge AC plasma display device as claimed in claim 14, wherein said memory means is constituted by a vacant area of a driving wave-form memory device (55) in said plasma display device, and the information on the number of sustain emissions in said each subframe is set in the vacant area of said driving wave-form memory device (55).

16. A three-electrode surface-discharge AC plasma display device as claimed in claim 14, wherein said plasma display device further comprises a brightness controller (51) for adjusting the brightness, and said brightness controller (51) selects one piece from the information on the number of sustain emissions in said each subframe set in said memory means (55).

17. A three-electrode surface-discharge AC plasma display device as claimed in claim 14, wherein the number of sustain emissions in said each subframe is set as a plurality of combinations in said memory means (55), and an arbitrary one of said plurality of combinations is selected by means of selection signals supplied from the outside of said plasma display device.

18. A three-electrode surface-discharge AC plasma display device as claimed in claim 14, wherein said plasma display device further comprises a consumed current controller means (44) for controlling and keeping the consumed current below a predetermined value, the number of sustain emissions in said each subframe is set as a plurality of combinations in said memory means (55), an arbitrary one of said plurality of combinations is selected in response to the output from said consumed current controller means (44), and thereby the power consumption is kept constant regardless of the change of display rate.

19. A three-electrode surface-discharge AC plasma display device as claimed in claim 14, wherein the information on the number of sustain emissions in said each subframe is supplied from the outside of said plasma display device.

Fig.1

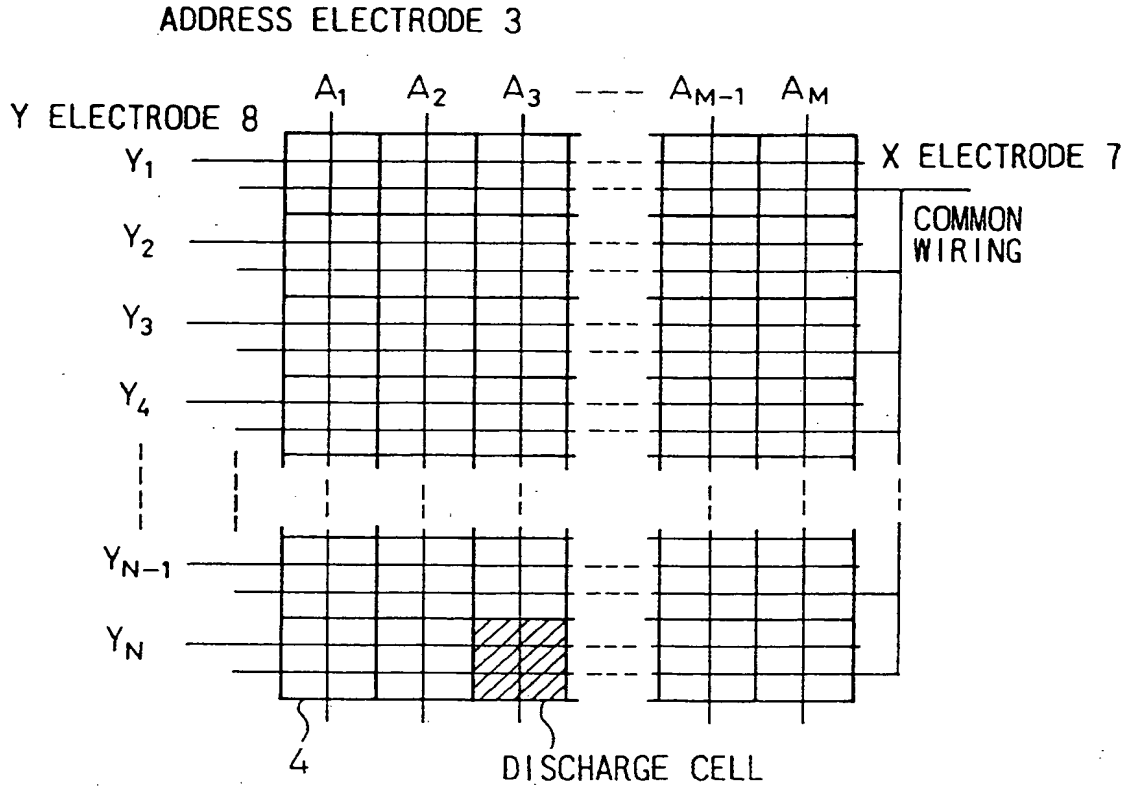

ADDRESS ELECTRODE 3
A1
A2
A3
AM-1
AM
Y ELECTRODE 8
Y1
Y2
Y3
Y4
YN-1
YN
X ELECTRODE 7
COMMON WIRING
4
DISCHARGE CELL

Fig.2

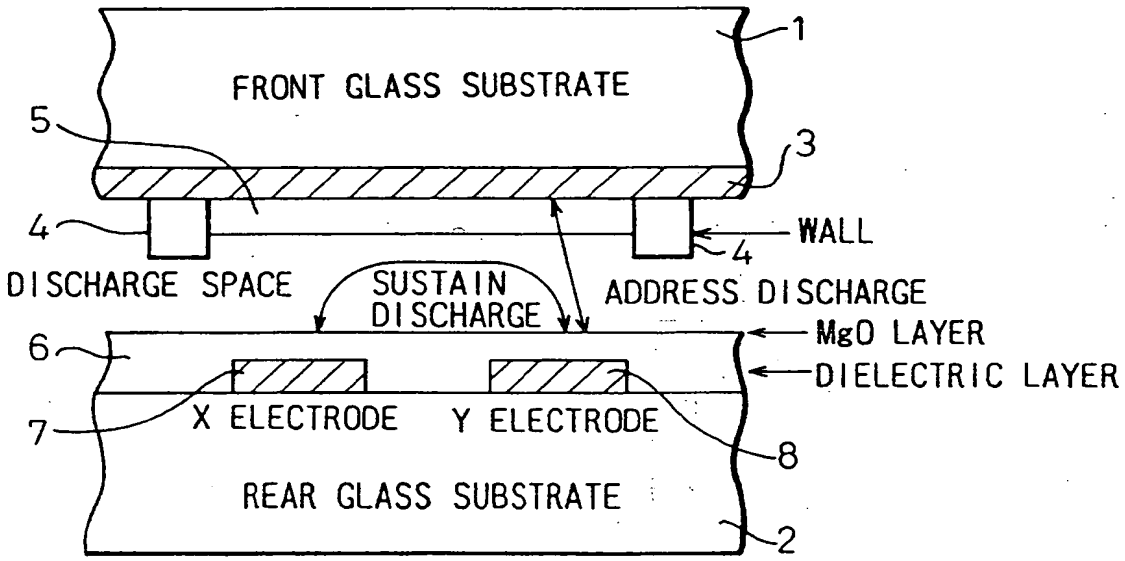
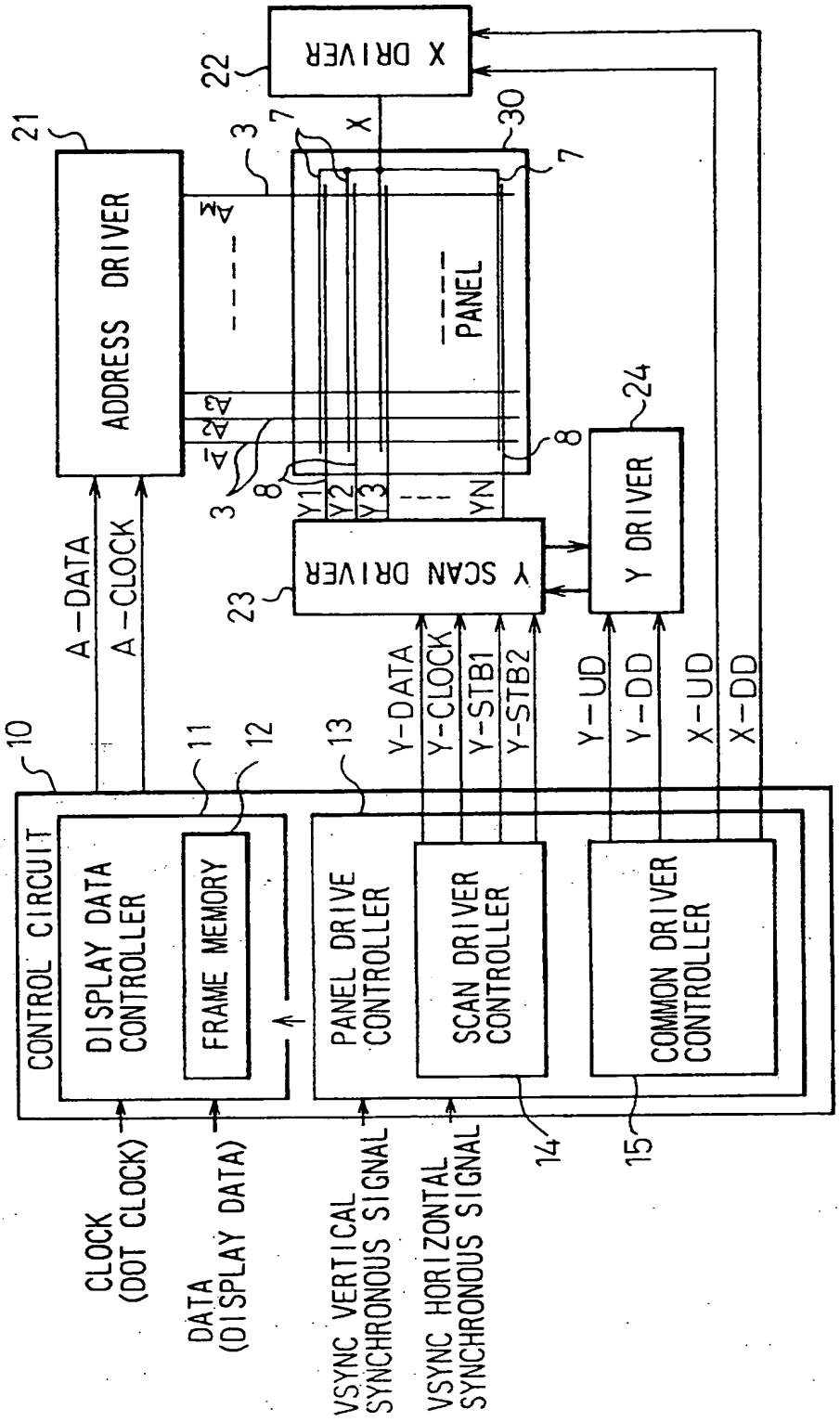

FRONT GLASS SUBSTRATE
1
5
3
4
WALL
4
DISCHARGE SPACE
SUSTAIN DISCHARGE
ADDRESS DISCHARGE
6
MgO LAYER
DIELECTRIC LAYER
7
X ELECTRODE
Y ELECTRODE
8
REAR GLASS SUBSTRATE
2

Fig.3


X DRIVER
22
21
ADDRESS DRIVER
PANEL
30
7
3
X
Y1
Y2
Y3
YN
8
24
Y DRIVER
Y SCAN DRIVER
23
A-DATA
A-CLOCK
Y-DATA
Y-CLOCK
Y-STB1
Y-STB2
Y-UD
Y-DD
X-UD
X-DD
10
11
12
13
CONTROL CIRCUIT
DISPLAY DATA CONTROLLER
FRAME MEMORY
PANEL DRIVE CONTROLLER
SCAN DRIVER CONTROLLER
COMMON DRIVER CONTROLLER
14
15
CLOCK (DOT CLOCK)
DATA (DISPLAY DATA)
VSYNC VERTICAL SYNCHRONOUS SIGNAL
VSYNC HORIZONTAL SYNCHRONOUS SIGNAL

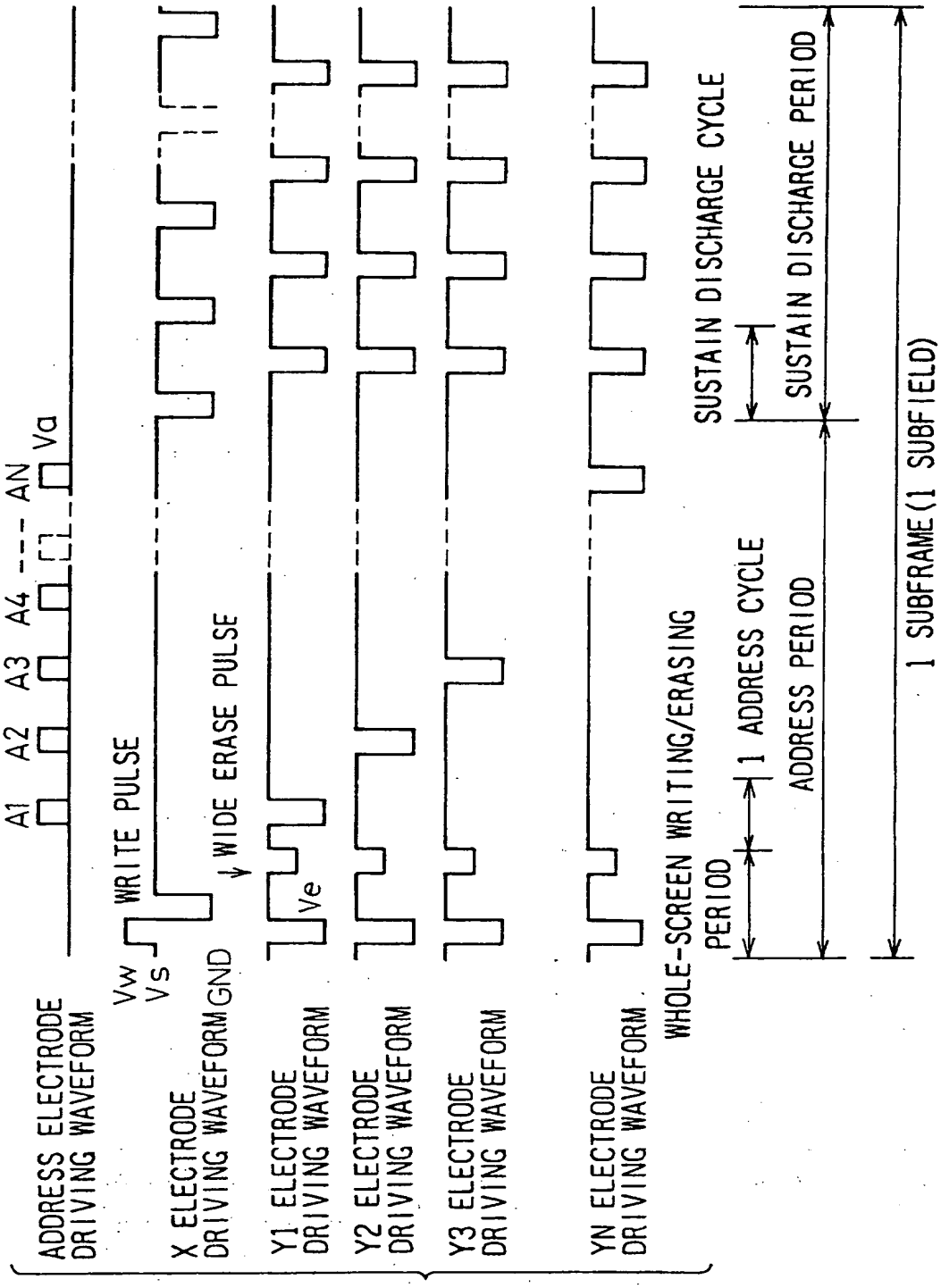

ADDRESS ELECTRODE DRIVING WAVEFORM
A1
A2
A3
A4
--- AN
Va
WRITE PULSE
Vw
Vs
WIDE ERASE PULSE
X ELECTRODE DRIVING WAVEFORM
GND
Ve
Y1 ELECTRODE DRIVING WAVEFORM
Y2 ELECTRODE DRIVING WAVEFORM
Y3 ELECTRODE DRIVING WAVEFORM
YN ELECTRODE DRIVING WAVEFORM
WHOLE-SCREEN WRITING/ERASING PERIOD
1 ADDRESS CYCLE
ADDRESS PERIOD
SUSTAIN DISCHARGE CYCLE
SUSTAIN DISCHARGE PERIOD
1 SUBFRAME(1 SUBFIELD)

Fig.4

Fig.5A

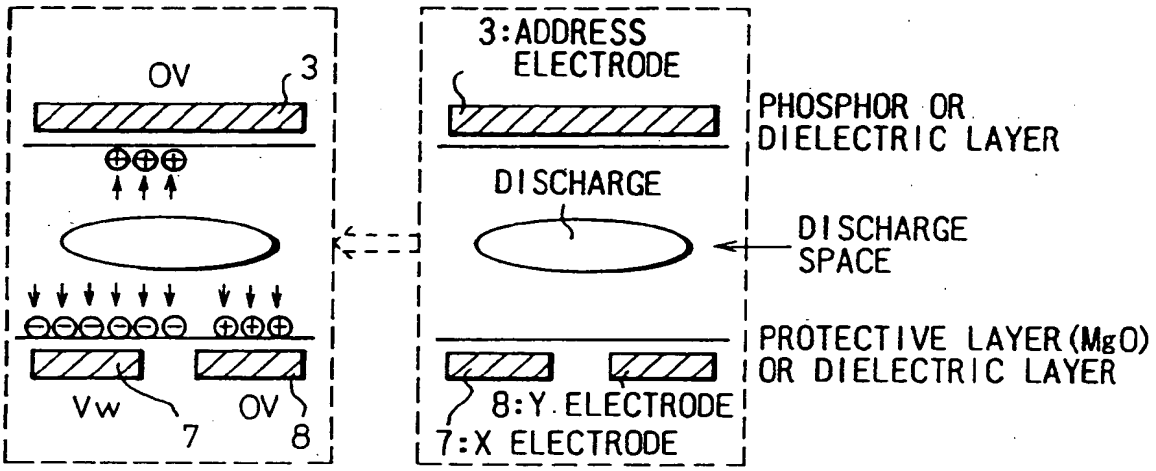


Fig.5B

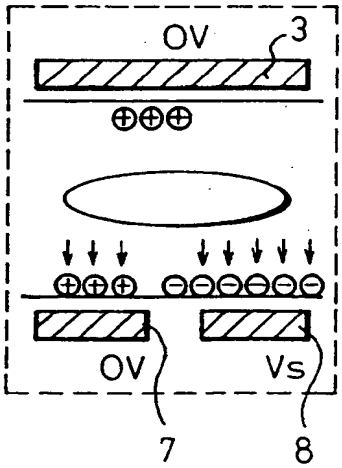


Fig.5C

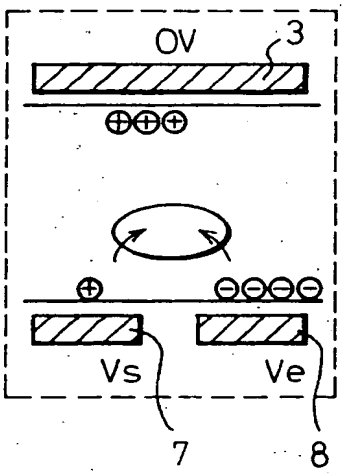


Fig.5D

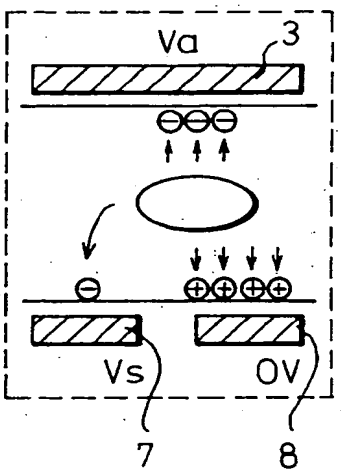
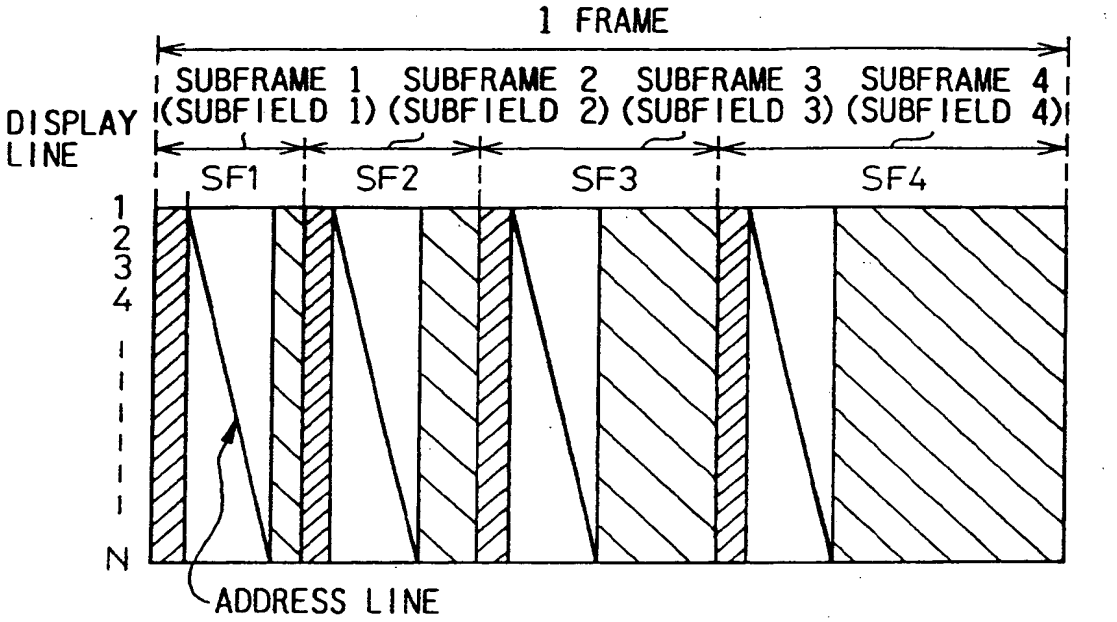


Fig.6



WHOLE-SCREEN WRITING
ADDRESS
ADDRESS PERIOD
(SELF-ERASE ADDRESS IN A LINE SEQUENCE)

* TO CAUSE WRITING DISCHARGE ALL OVER THE SCREEN, AND SELECT DISPLAY CELLS LINE BY LINE

SUSTAIN DISCHARGE PERIOD

* THE NUMBER OF SUSTAIN DISCHARGES OF EACH SUBFRAME (OR SUBFIELD) IS OF THE RATE 1:2:4:8

Fig.7

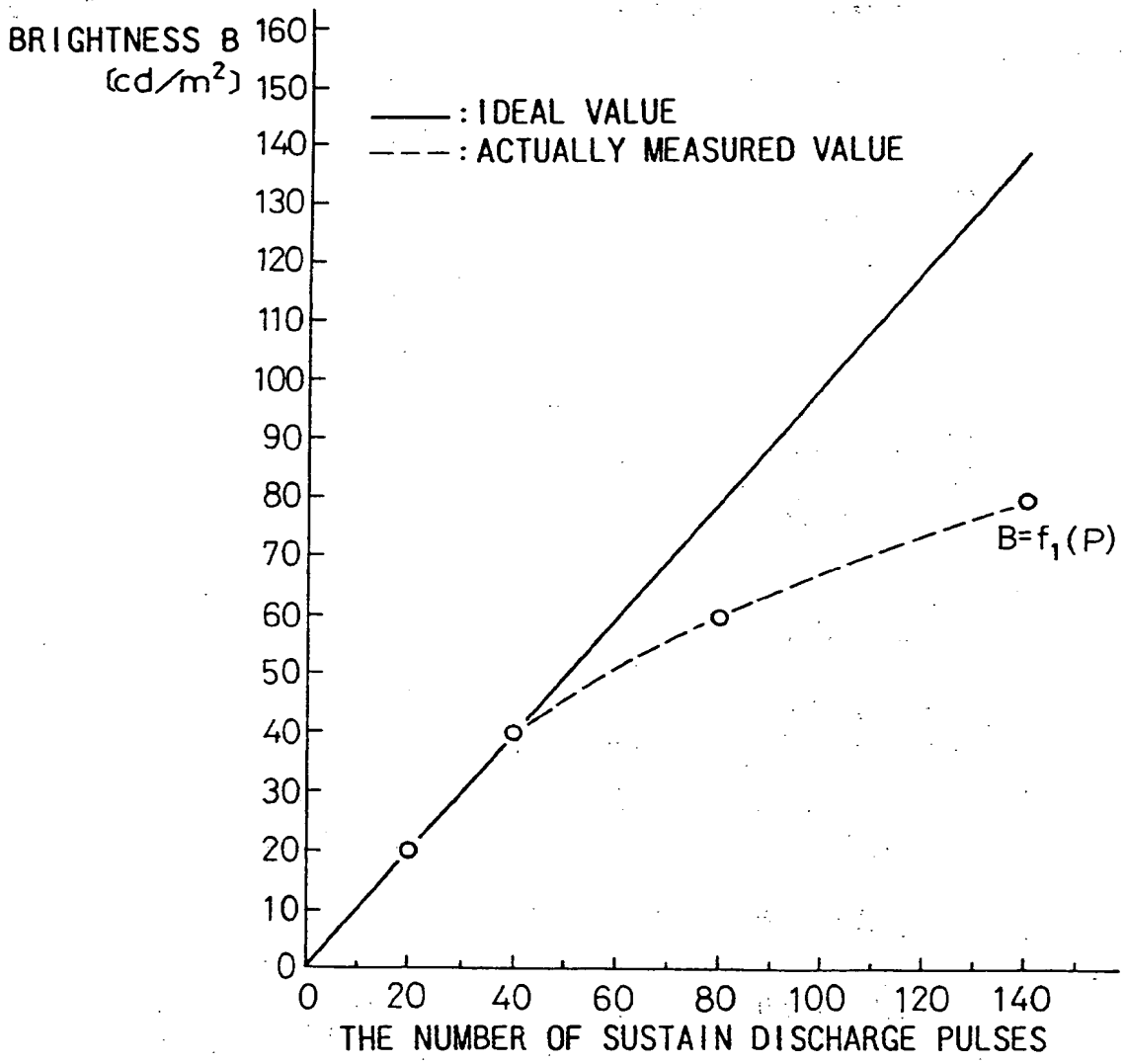

BRIGHTNESS B
(cd/m²)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
——: IDEAL VALUE
– – –: ACTUALLY MEASURED VALUE
B=f₁(P)
0
20
40
60
80
100
120
140
THE NUMBER OF SUSTAIN DISCHARGE PULSES

Fig.8

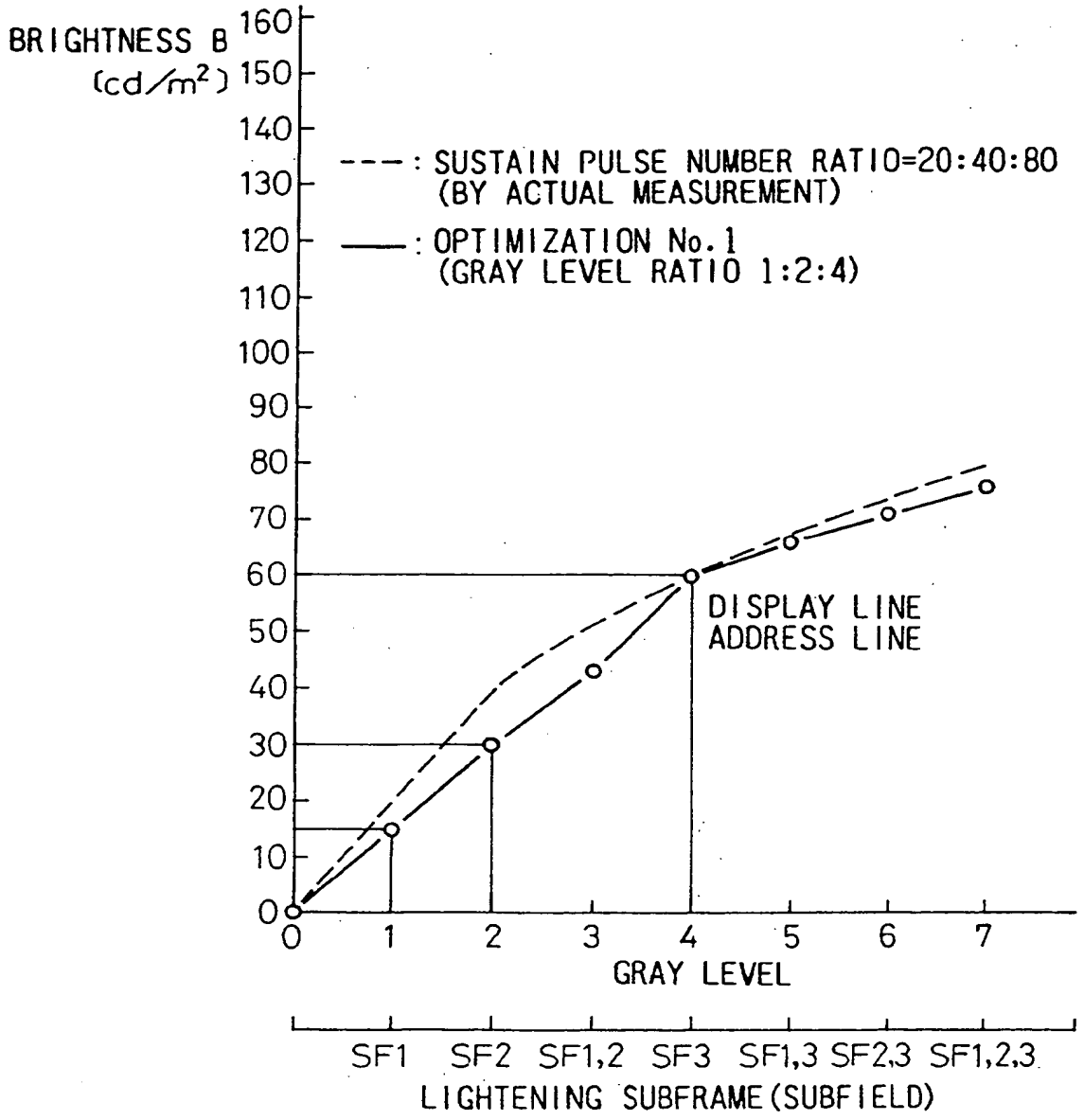

BRIGHTNESS B
(cd/m²)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
---: SUSTAIN PULSE NUMBER RATIO=20:40:80
(BY ACTUAL MEASUREMENT)
——: OPTIMIZATION No.1
(GRAY LEVEL RATIO 1:2:4)
DISPLAY LINE
ADDRESS LINE
0 1 2 3 4 5 6 7
GRAY LEVEL
SF1 SF2 SF1,2 SF3 SF1,3 SF2,3 SF1,2,3
LIGHTENING SUBFRAME(SUBFIELD)

Fig.9

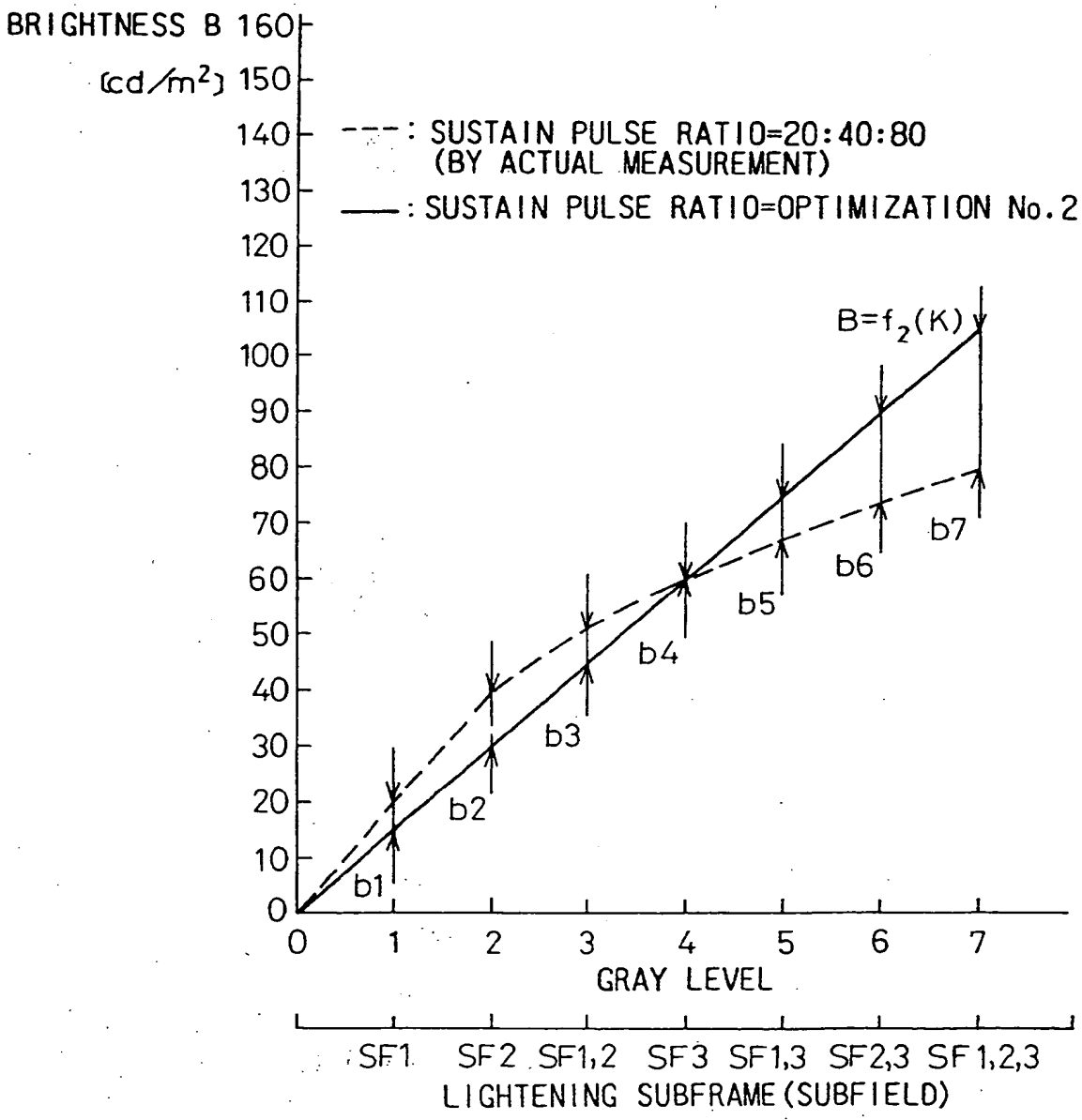

BRIGHTNESS B
(cd/m²)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
---: SUSTAIN PULSE RATIO=20:40:80
(BY ACTUAL MEASUREMENT)
——: SUSTAIN PULSE RATIO=OPTIMIZATION No.2
B=f2(K)
b1
b2
b3
b4
b5
b6
b7
0 1 2 3 4 5 6 7
GRAY LEVEL
SF1 SF2 SF1,2 SF3 SF1,3 SF2,3 SF1,2,3
LIGHTENING SUBFRAME (SUBFIELD)

Fig.10

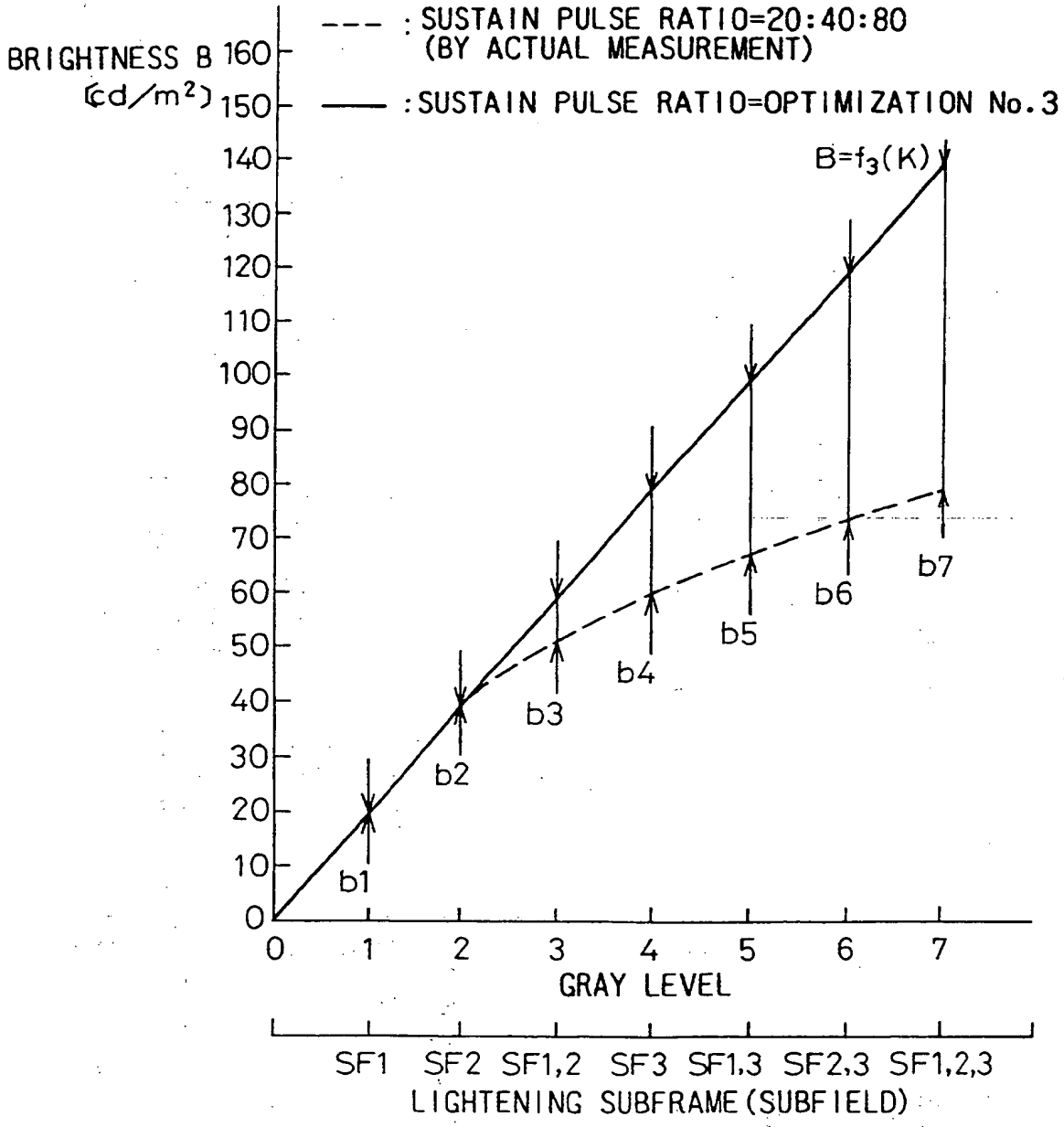

--- : SUSTAIN PULSE RATIO=20:40:80
(BY ACTUAL MEASUREMENT)
—— : SUSTAIN PULSE RATIO=OPTIMIZATION No.3
BRIGHTNESS B (cd/m²)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
B=f3(K)
b1
b2
b3
b4
b5
b6
b7
0 1 2 3 4 5 6 7
GRAY LEVEL
SF1 SF2 SF1,2 SF3 SF1,3 SF2,3 SF1,2,3
LIGHTENING SUBFRAME (SUBFIELD)

Fig.11A

Fig.11

Fig.11A	Fig.11B

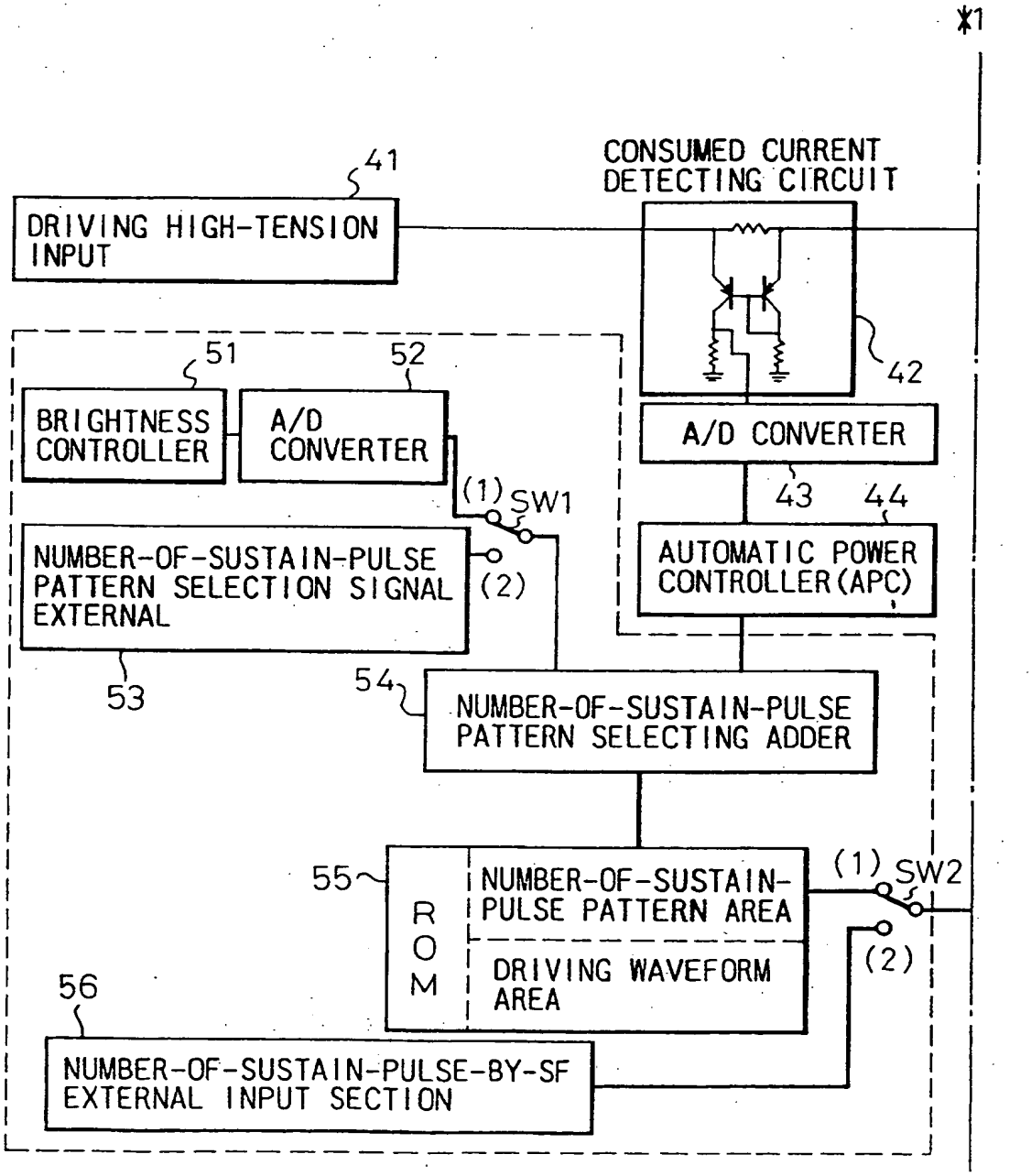
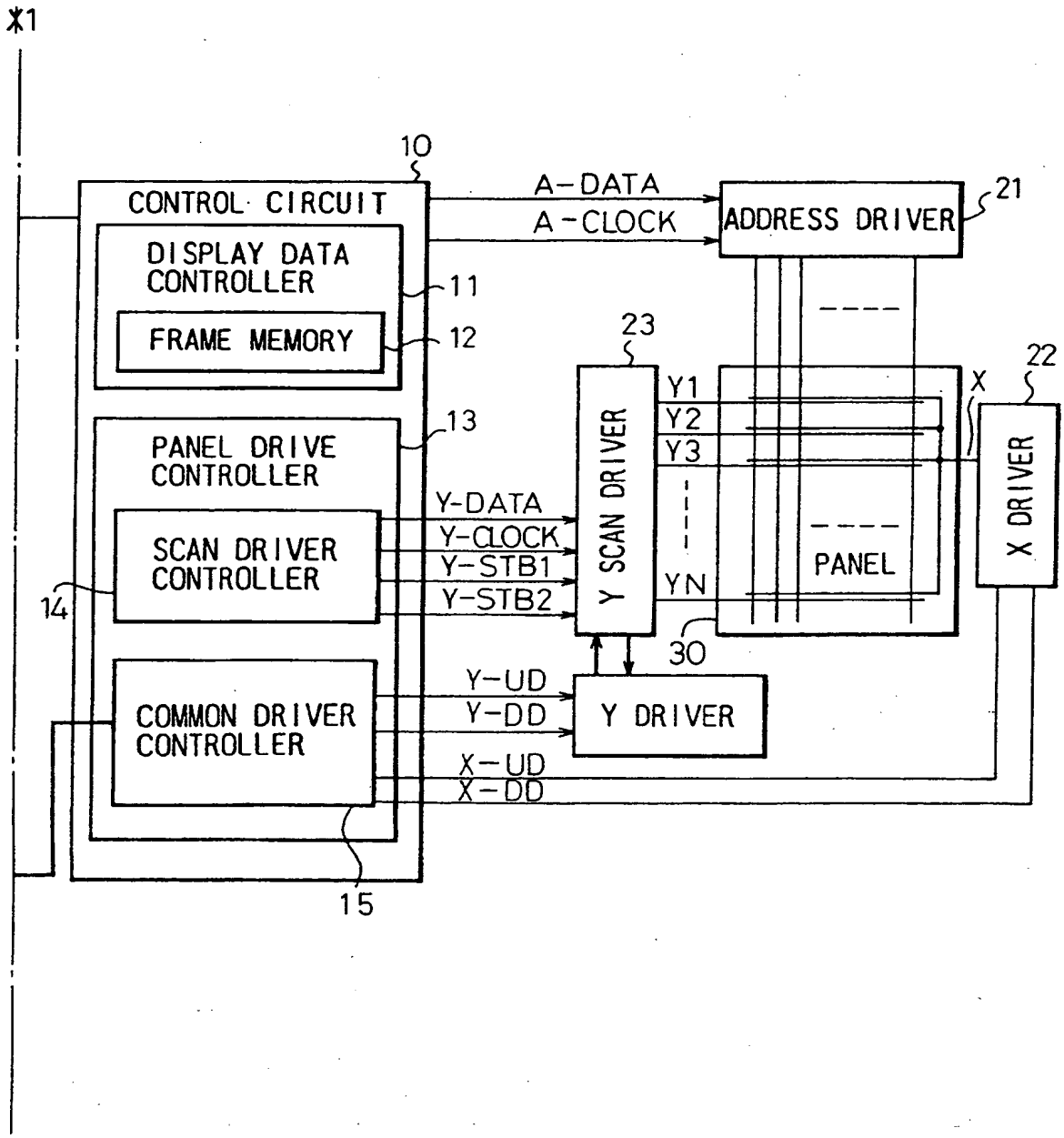


Fig.11B


*1
10
CONTROL CIRCUIT
DISPLAY DATA CONTROLLER
11
FRAME MEMORY
12
13
PANEL DRIVE CONTROLLER
SCAN DRIVER CONTROLLER
14
COMMON DRIVER CONTROLLER
15
A-DATA
A-CLOCK
ADDRESS DRIVER
21
23
Y SCAN DRIVER
Y1
Y2
Y3
YN
Y-DATA
Y-CLOCK
Y-STB1
Y-STB2
Y-UD
Y-DD
Y DRIVER
30
PANEL
X
22
X DRIVER
X-UD
X-DD

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 653 740 A3

(12) EUROPEAN PATENT APPLICATION

(88) Date of publication A3:
26.06.1996 Bulletin 1996/26

(43) Date of publication A2:
17.05.1995 Bulletin 1995/20

(21) Application number: **94300695.7**

(22) Date of filing: **31.01.1994**

(51) Int. Cl.[6]: **G09G 3/28**

(84) Designated Contracting States:
DE FR GB

(30) Priority: **17.11.1993 JP 288345/93**

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(54) Controlling the gray scale of plasma display devices

(57) A method of controlling the gray scale of a plasma display device has a forming step of forming a frame for an image by a plurality of subframes each having a different brightness, a setting step of setting the number of sustain emissions of the each subframe individually for each subframe, and a displaying step of displaying the image on the plasma display device by a gray scale display having a specific brightness. The number of sustain emissions in each subframe is set individually by the individual subframe, and this can establish a linear relation between the gray level and the corresponding brightness. Therefore, an enhancement of display quality of the plasma display device can be realized.

Fig.11A

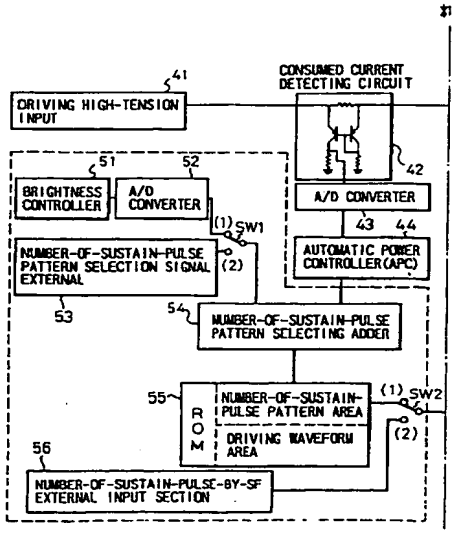

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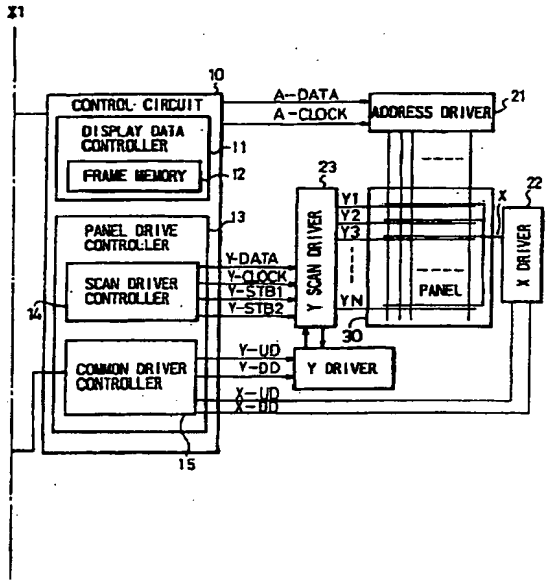
Fig.11B


X1
10
CONTROL CIRCUIT
DISPLAY DATA CONTROLLER
11
FRAME MEMORY
12
PANEL DRIVE CONTROLLER
13
SCAN DRIVER CONTROLLER
14
COMMON DRIVER CONTROLLER
15
A-DATA
A-CLOCK
ADDRESS DRIVER
21
Y-DATA
Y-CLOCK
Y-STB1
Y-STB2
Y-UD
Y-DD
X-UD
X-DD
Y SCAN DRIVER
23
Y DRIVER
30
Y1
Y2
Y3
YN
PANEL
X
22
X DRIVER

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 30 0695

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
D,X	EP-A-0 488 891 (FUJITSU LIMITED)	1-5,12, 13	G09G3/28
A	* page 4, line 16 - page 5, line 26 * * page 6, line 51 - line 55 * -----	6-11, 14-19	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

G09G

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	3 May 1996	Farricella, L

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

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